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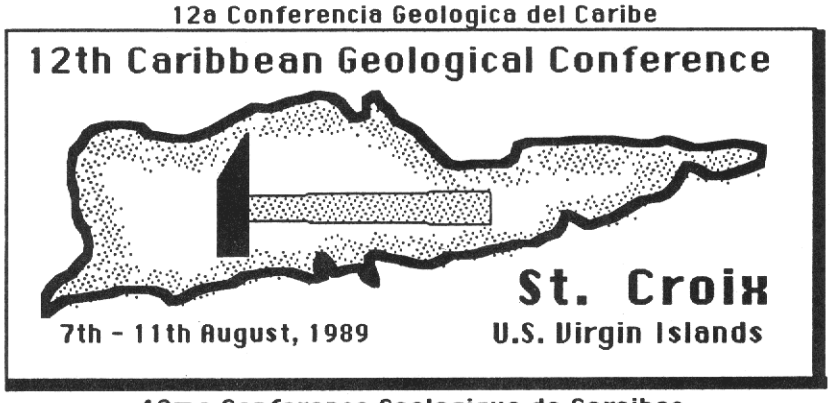

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EXPLOITATION OF THE MIDDLE MIOCENE OIL BEARING INTERMEDIATE HERRERA SANDSTONE RESERVOIRS IN TRINIDAD, WEST INDIES

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ABSTRACT

The Herrera sands contain the major oil producing reservoirs of Miocene age in Trinidad's Southern Basin. They lie within the Upper Cipero shale formation in the Penal/Wilson, Barrackpore/Mandingo and Ortoire fields of south-central Trinidad. These turbidite sands are found at three levels - the "overthrust", "intermediate" and "underthrust" - each level separated by a major thrust fault and associated with a complex structure of a strong overfold and recumbent syncline formed by major tectonic movements at the end of Middle Miocene time.

The Intermediate Herrera sands are confined to a long (17 miles) and narrow (2,000 feet) area trending NE-SW from the Penal/Wilson field to the Barrackpore/Mandingo field. The sands are found at depths of 6,000 to 10,000 feet in a complex structure which plunges to the south-west and is cut by numerous extensional cross faults which delineate separate hydrocarbon pools. Exploration commenced in 1946 and by December 31, 1988 cumulative production was 18 million barrels of oil/condensate and 30 BCF of natural gas. These sands offer the best potential for continued exploitation of an additional 19.5 MM barrels of undeveloped oil/condensate reserves.

INTRODUCTION

Trinidad is located in the south-east corner of the Caribbean and within the eastern Venezuelan Basin (Fig. 1). Geologically, Trinidad has very similar features to Venezuela, having been subjected to the same kind of compressive stress from the north north-west resulting in wrench faults and NE-SW trending folds and thrust faults which are directly associated with oil accumulations in the Miocene age reservoirs of Nariva, Retrench and Herrera sands (Fig. 2).

The Herrera sands are the most important and contain the major oil producing reservoirs of Miocene age in Trinidad's Southern Basin. They lie within the Upper Cipero shale formation in the Penal/Wilson, Barrackpore/Mandingo and Ortoire fields of Southern Trinidad (Fig. 3).

These turbidite sands are found at three levels - the "overthrust", "intermediate" and "underthrust" - each level separated by a major thrust fault. The Intermediate Herrera sands have been exploited in the Penal/Wilson and Barrackpore/Mandingo fields.

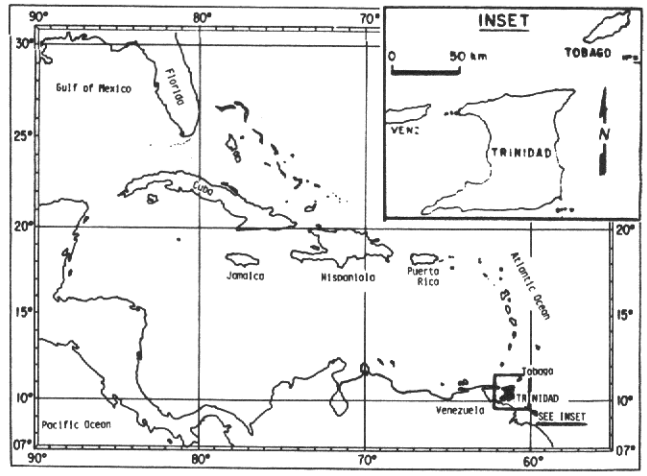

Fig. 1 Location Map showing Trinidad and the Caribbean.

HISTORY OF FIELD DEVELOPMENT

The "overthrust" or shallow Herrera sands were first discovered in 1938 by Shell Oil Company in Penal-23 well. Development drilling of this field continued until 1946 when a field extension well, Penal-92, found the sands missing. The well was deepened to discover the second level or Intermediate Herrera sands well developed and oil bearing below a major thrust fault (Fig. 4). The field was BP-360 drilled in 1954 by the Trinidad leaseholds Ltd. Company which was exploiting the shallow Herrera sands in the area (Fig. 5). Exploitation drilling since then established that the Intermediate Herrera sands are confined to a long (17 miles) and narrow (2,000 feet) area extending from Penal field to the Barrackpore/Mandingo field.

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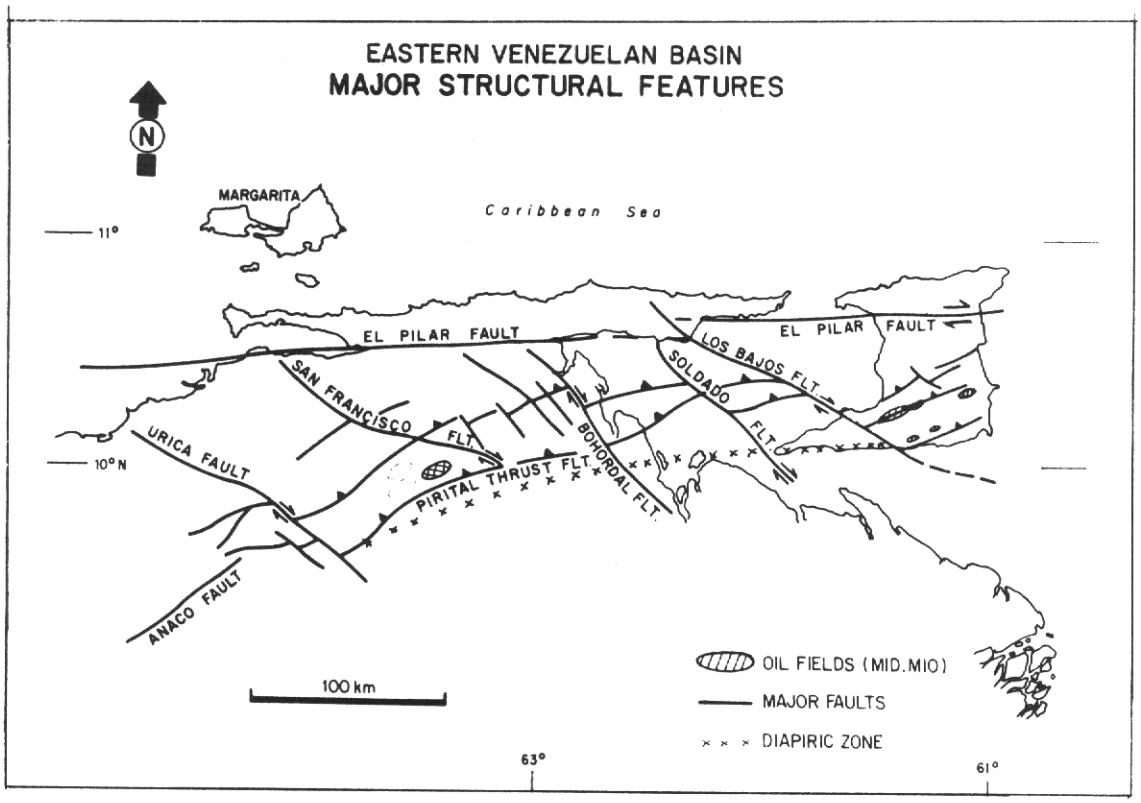


Fig. 2 Regional Map showing the major wrench and thrust faults in Trinidad and Eastern Venezuela.

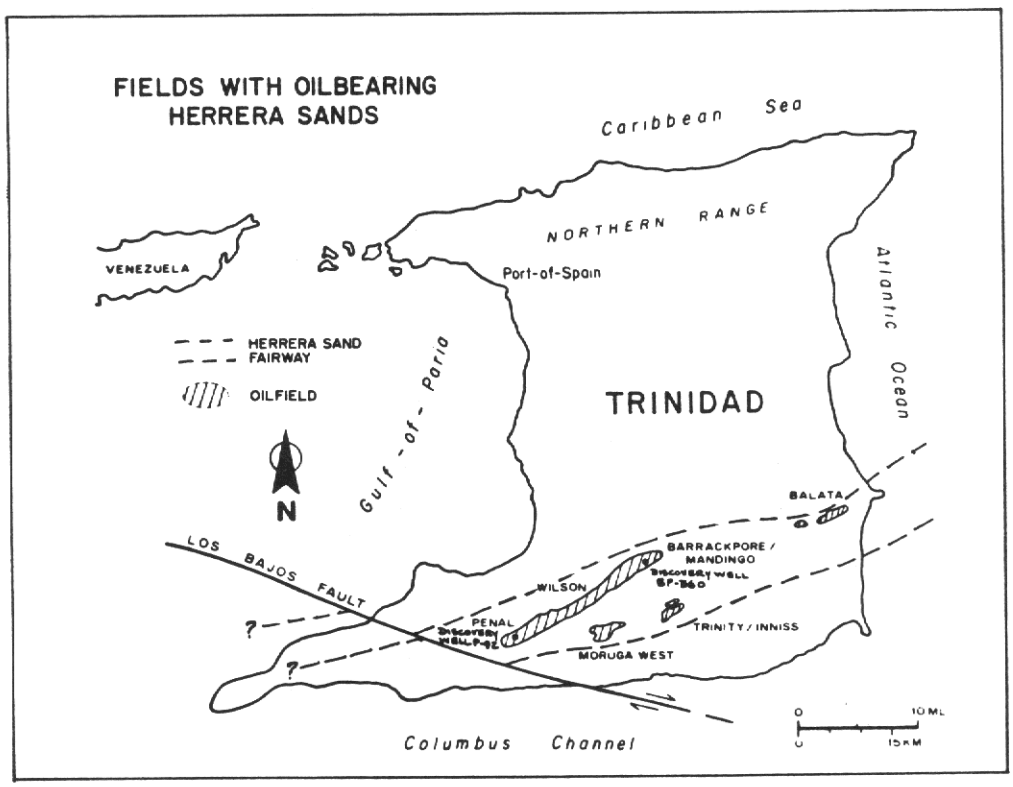


Fig. 3 Location Map showing the fields with oilbearing Herrera sands in Trinidad's Southern Basin.

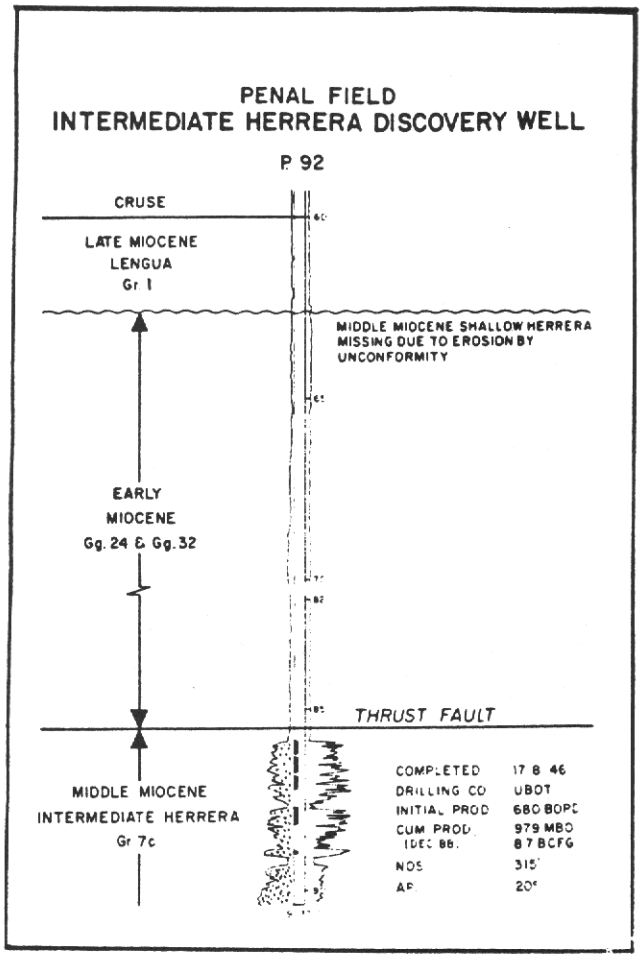


Fig. 4 Gamma Ray-Induction Resistivity Log of Penal-92 well showing well developed Middle Miocene Intermediate Herrera sands.

LITHOLOGY

The Herrera sandstone is generally described as grey, calcareous, fine to coarse and even conglomeratic with a "pepper and salt" appearance. The black "pepper" appearance is due to chert, hard black shale, black limestone and coal fragments. The white "salt" appearance is due to clear quartz grains. The Intermediate Herrera sands range from coarse to very fine grained sands and even siltsize in some areas.

REGIONAL STRATIGRAPHY

The Herrera sands are developed within the Middle Miocene Globorotalia Fohsi zone which form the Upper part of the Cipero formation. The sands were deposited in a marine bathyal environment where the presence of planktonic formaninifera enables zonation using the evolutionary sequence of the Globorotalia Fohsi foraminifera group (Fig. 6).

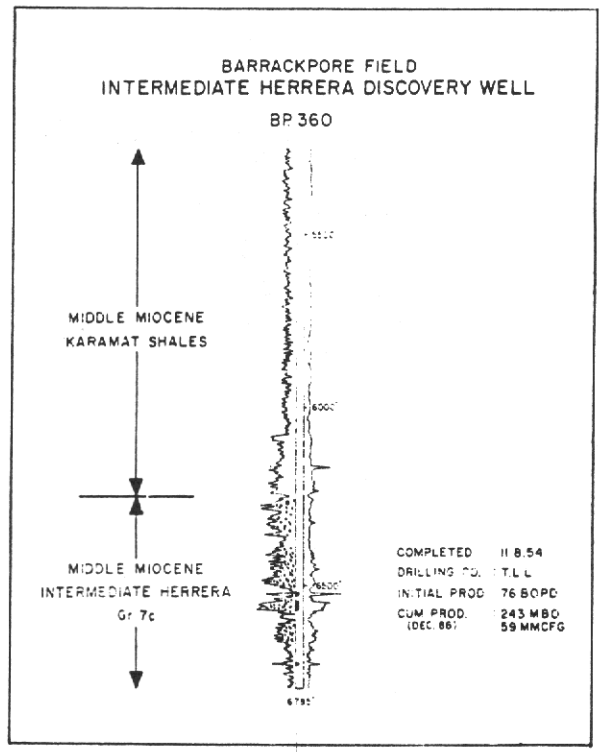


Fig. 5 Gamma Ray-Induction Resistivity Log of Barrackpore-360 well.

Work done by previous authors including P. Bitterli (1958) and W.G. Poole (1965) have already established that the Herrera sands were initially deposited in shallow water and were then transported by turbidity currents into the deeper water environment where they were encased within the Upper Cipero shales. A schematic diagram (Fig. 7) shows the author's model for deposition suggesting a north-westerly source for the Herrera sands which were transported to the shelf edge before being redistributed by turbidity currents into a deep water NE-SW trending trough.

STRUCTURE

At the end of Middle Miocene time, there was strong folding with compression from the north-west which resulted in a complex structure at the Herrera sand level involving a strong overfold with associated faulting and thrusting. A series of NE-SW trending thrust faults developed across Trinidad's Southern Basin. These faults with their associated anticlinal structures provided the traps for oil accumulation in the Intermediate Herrera sands found in an area extending for 17 miles long from south-west Penal to Mandingo field. Using well logs, production data and planktonic foraminiferal zones, the structure of the Intermediate Herrera sands has been mapped over the study area. The Intermediate Herrera sands will be described separately for the Penal/Wilson field and the Barrackpore/Mandingo field.

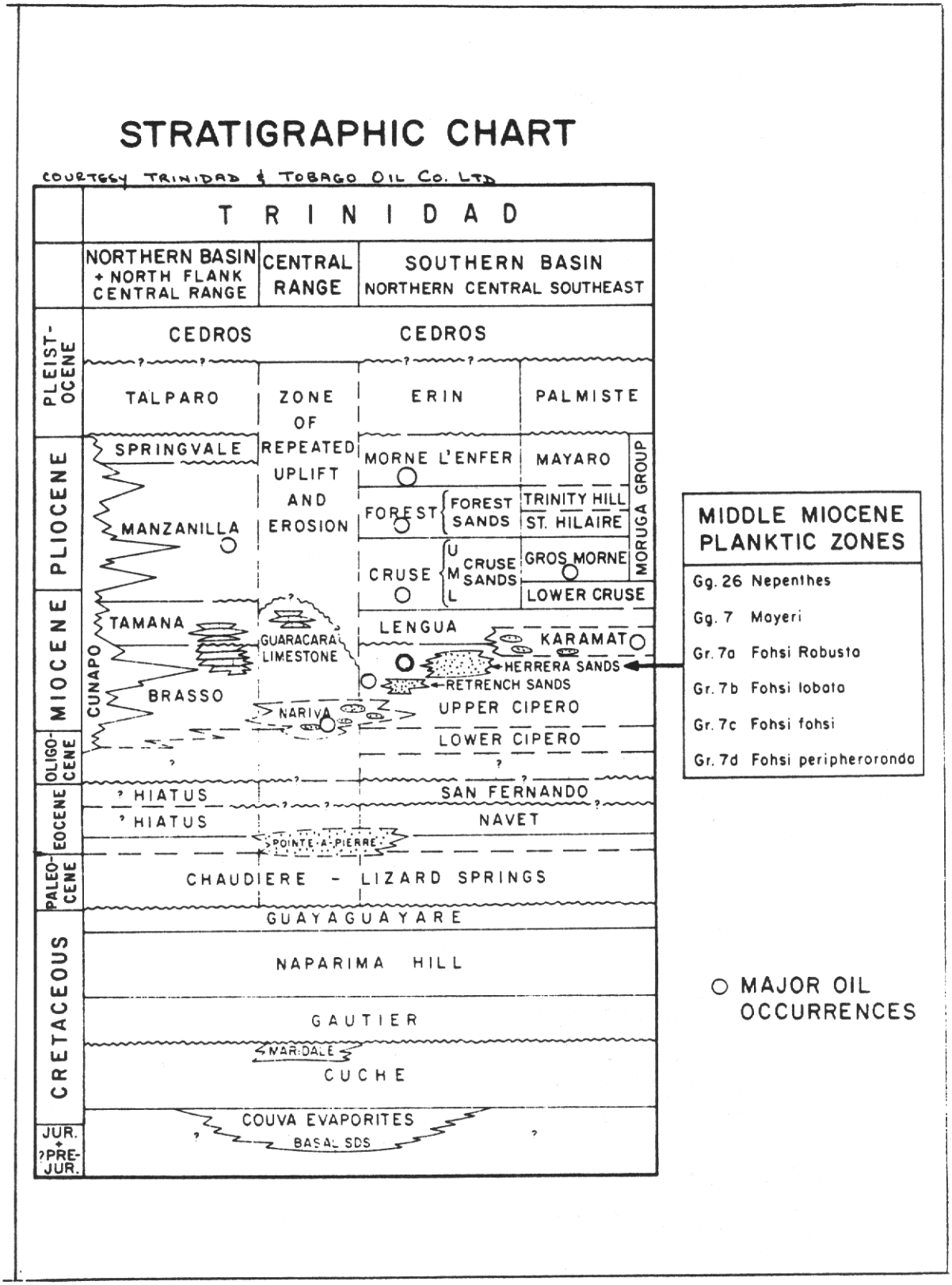
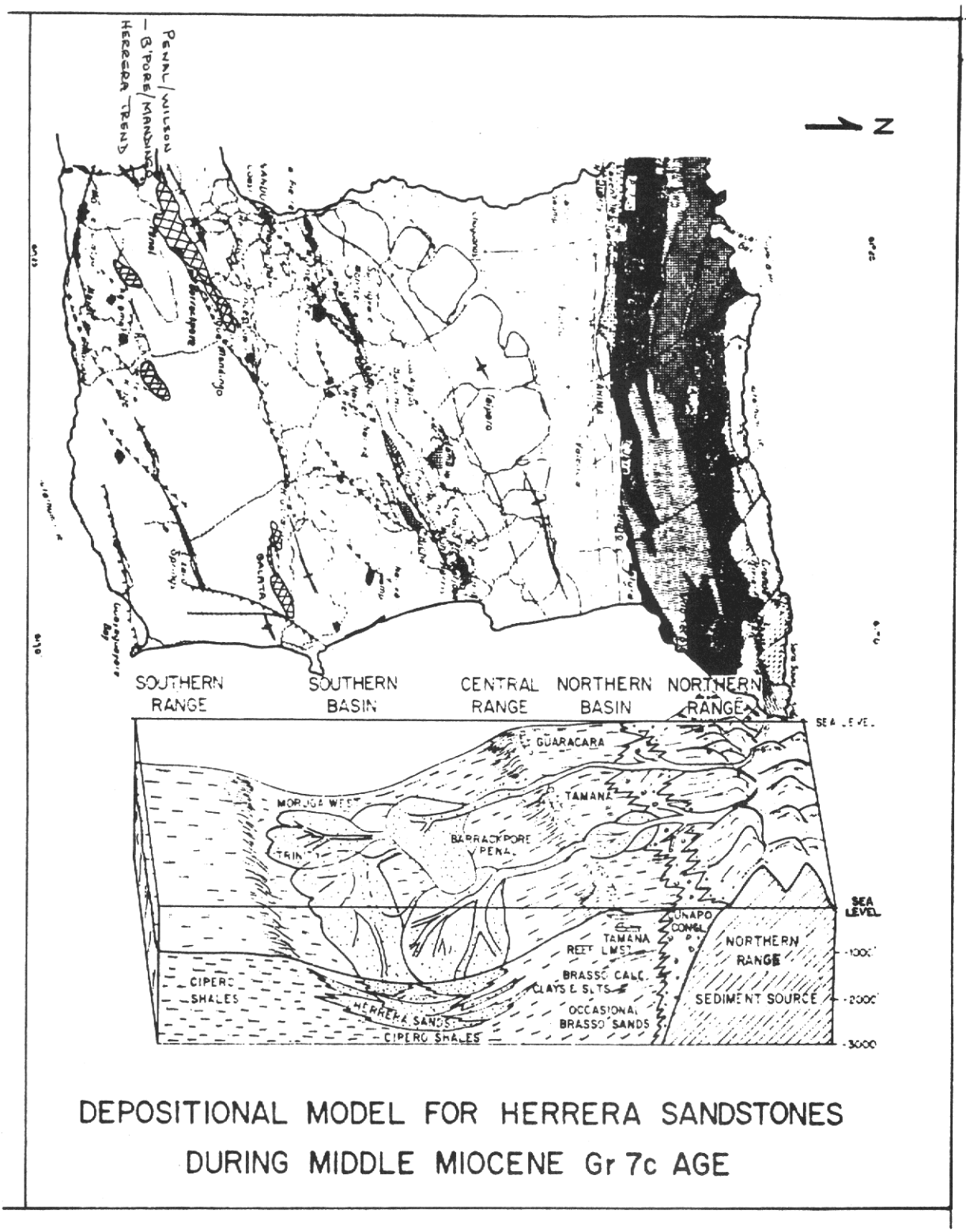


Fig. 6 Stratigraphic Chart of Trinidad. The Herrera sands are found within the Middle Miocene Upper Cipero formation.



DEPOSITIONAL MODEL FOR HERRERA SANDSTONES DURING MIDDLE MIOCENE Gr 7c AGE

Fig. 7 Depositional Model for the Herrera sands during Middle Miocene Gr 7c age suggest a source from the north-west. Cherts were probably sourced from Cretaceous rocks reworked along the Central Range high.

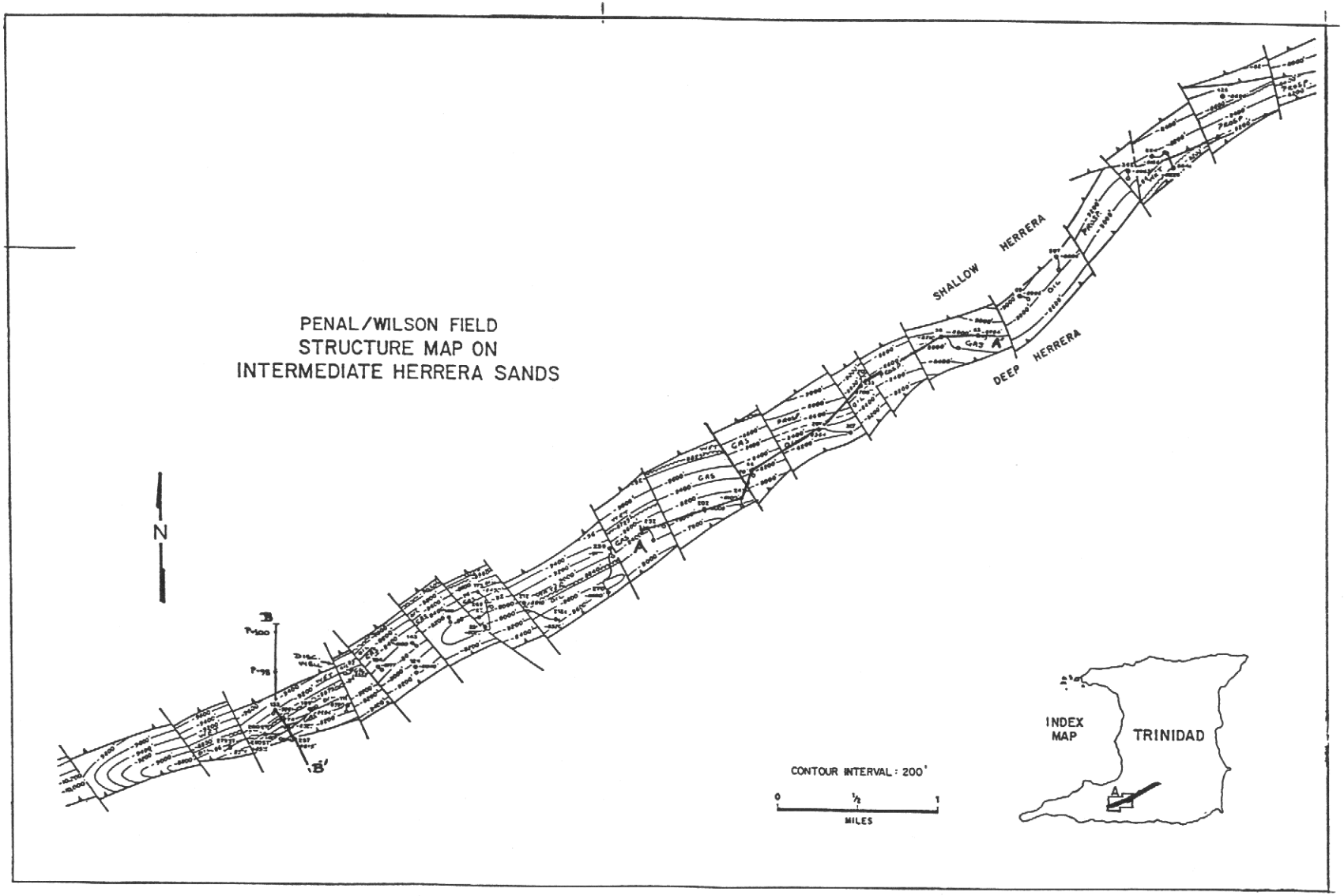


Fig. 8 Structure Map showing the Intermediate Herrera sands between the NE-SW trending thrust faults and NW-SE normal faults. Sands dip to the north-west and are overturned in the Penal area.

PENAL/WILSON FIELD

Structure

The Penal/Wilson field extends for approximately 7 miles over 1,260 acres in a north-east south-west direction (Fig. 8). In the south-west Penal area, the Intermediate Herrera sands have been inverted or overturned with dips ranging from 25° - 60° NW on the northern limb of a recumbent syncline, the axis of which lies within the deep or "underthrust" Herrera sands. The Intermediate Herrera sands are found between two major thrust faults which hade to the north-west and terminate against the Middle Miocene unconformity. In addition to these thrust faults which act as the northern and southern limits of the sands, there are many NW-SE trending normal faults which act as barriers to form separate hydrocarbon accumulations with different formation pressures and water levels (Figs. 9 and 10). The Wilson field is an extension of the Penal field to the north-east where the sands are not overturned but still dip to the north-west.

Stratigraphy

The Intermediate Herrera sands extend over the Penal/Wilson field varying from a massive sand section up to 600 feet thick to a thin sand 35 feet thick. Isopach mapping shows lobes of turbidite sands trending NE-SW and separated in places by areas of thin sand deposition (Fig. 11). Sand thicknesses have been reduced in some wells due to faulting out by the upper and lower thrust faults. Sand packages generally appear to be more continuous in an NE-SW direction (Fig. 12). Wherever the Intermediate Herrera sands are encountered in the same well with the "underthrust" deep Herrera sands, the latter are generally wet as they are in a structurally downdip position (Fig. 13).

Hydrocarbon Manifestations

The hydrocarbons produced from the Penal/Wilson field range from 20° - 30° API black oil to 45° - 56° API condensate, together with associated natural gas. Studies of gravities and gas/oil ratios by L.H. Bolt (1958)-Shell Oil Co., and R. Attai and A. Russell (1984)-Trinidad and Tobago Oil Co. Ltd., indicate a gas/oil contact at approximately 8,575 feet in several fault blocks but varying in the others. The lightest fluid (condensate) and highest gas/oil ratios were found as expected in wells drilled high on the structure. The oil water contact was found to vary from block to block.

Production Characteristics

In the Penal field, the up-dip wells were closed in for gas conservation and to maintain reservoir pressure until the wells completed in the black oil reservoir became high gas/oil ratio producers. The gas/condensate reservoirs were then in the early 1970's produced for gas supplies with a yield of up to 35 bbls. condensate per million cu. ft. of gas. An important characteristic of the field is that the black oil reservoirs in some of the fault blocks e.g. P-175, 189, 279 and 212x, appeared to be reacting to a partial water drive with a slow BHP decline, constant GOR's and increasing water cuts. However, structural mapping of the wells in different fault blocks with varying water levels does not support this theory. Six wells in the field have each produced approximately 1 MMB of condensate with gas production ranging from 8 BCF to 30 BCF per well. Major characteristics of the Penal/Wilson field are summarised in Table 1.

RESERVES

By December 31, 1988, the Penal/Wilson field had produced 14.8 mmbbls. of oil/condensate and 260 BCF of natural gas from the Intermediate Herrera sands in only twenty-six wells.

Together with proven unrecovered reserves of 124 mbbls. of oil and potential possible reserves of 4.4 MMbbls. oil, the total reserves of the Penal/Wilson field are estimated at approximately 19.3 MMbbls. of oil/condensate and 264.5 BCF of natural gas (Table II).

BARRACKPORE/MANDINGO FIELD

Structure

The Barrackpore/Mandingo field extends for 3.75 miles with over 500 acres of productive oil-bearing Intermediate Herrera sands. The sands dip 20° - 25° NNW on the northern flank of a structure formed by NW dipping thrust faults, three of which were mapped in the west and four in the east (Fig. 14). The sands are not overturned and are separated by splay thrust faults which terminate against the Middle Miocene unconformity and which separate the deep Heerera sands to the south-east and the shallow Herrera sands to the north-west (Fig. 15). The field has also been subdivided by several NW-SE trending normal faults which are generally downthrown to the south-west. Small oil accumulations have been found in sands below the thrust fault (Fig. 16).

Stratigraphy

The Intermediate Herrera sands are found throughout the Barrackpore/Mandingo field and vary in thickness from 100 feet to 600 feet between the thrust faults which form the northern and southern boundaries. The sands here are encased within the Cipero shales which in turn undelie the Karamat shales which are characteristic to this area. These karamat shales are well known for its difficult drilling conditions related to swelling shales due to water absorption. Isopach mapping indicates the sands are more continuous in a NE-SW direction supporting deposition in that direction (Figs. 17 and 18).

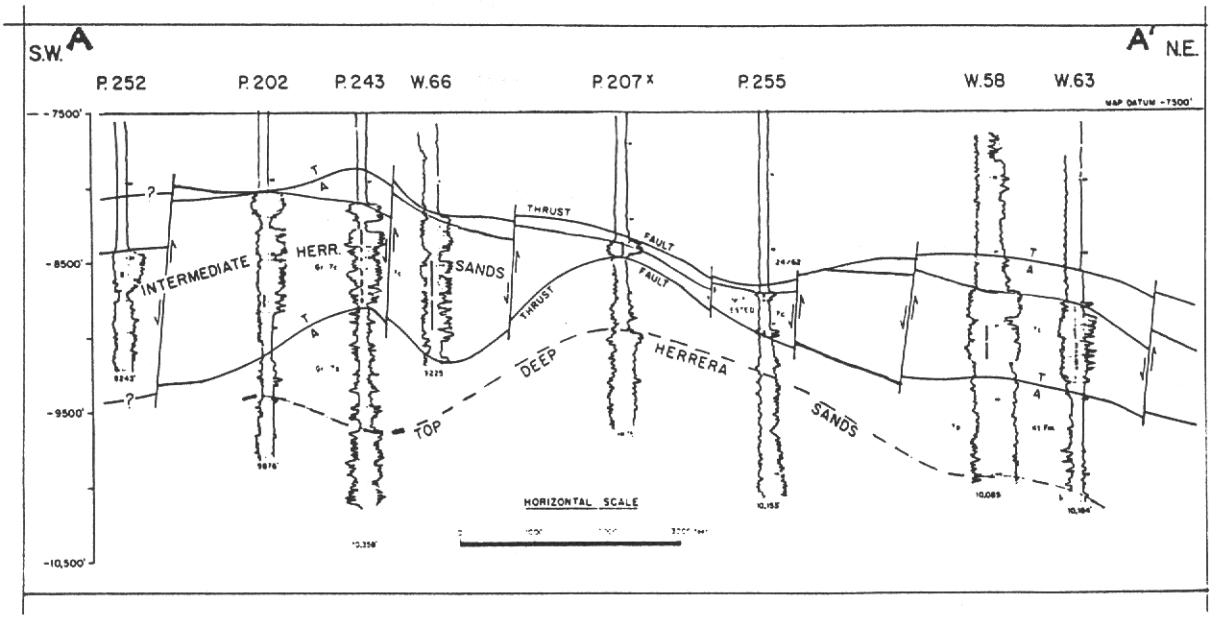


Fig. 9 Strike Section showing Upper and Lower thrust faults displaced by later normal faults.

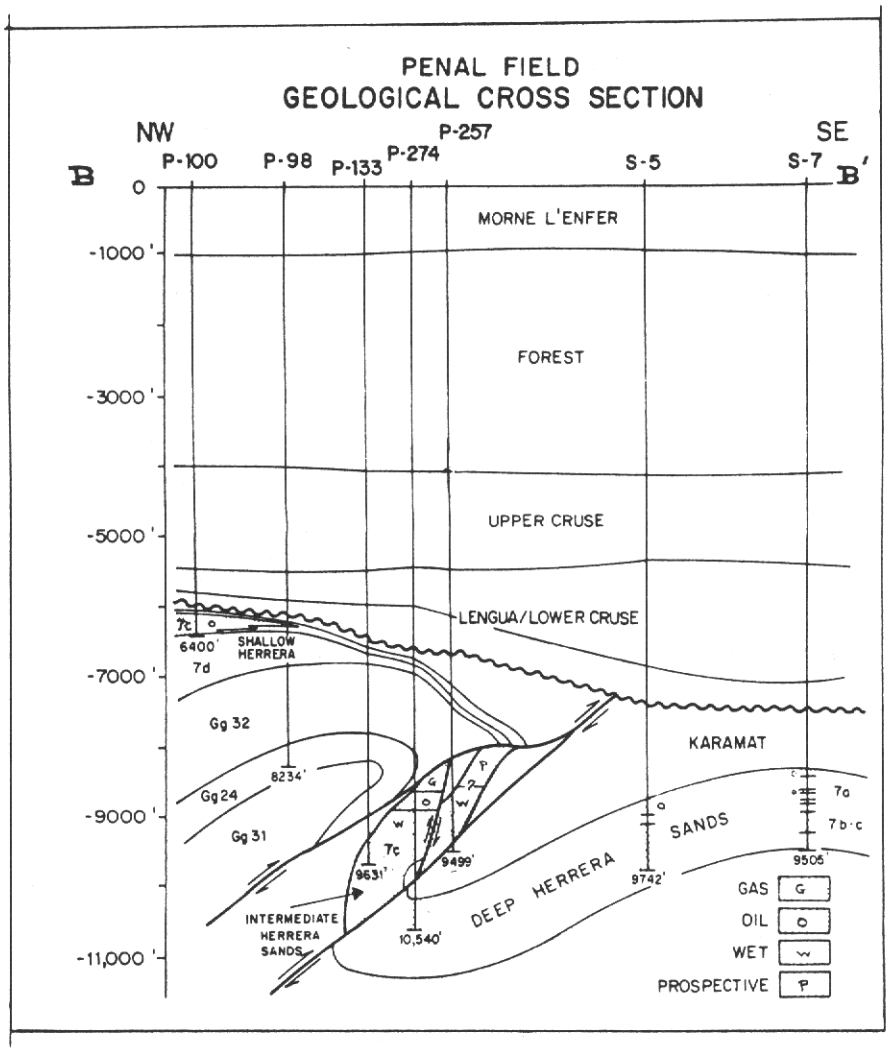


Fig. 10 Overturned Intermediate Herrera sands between two thrust faults in the Penal area.

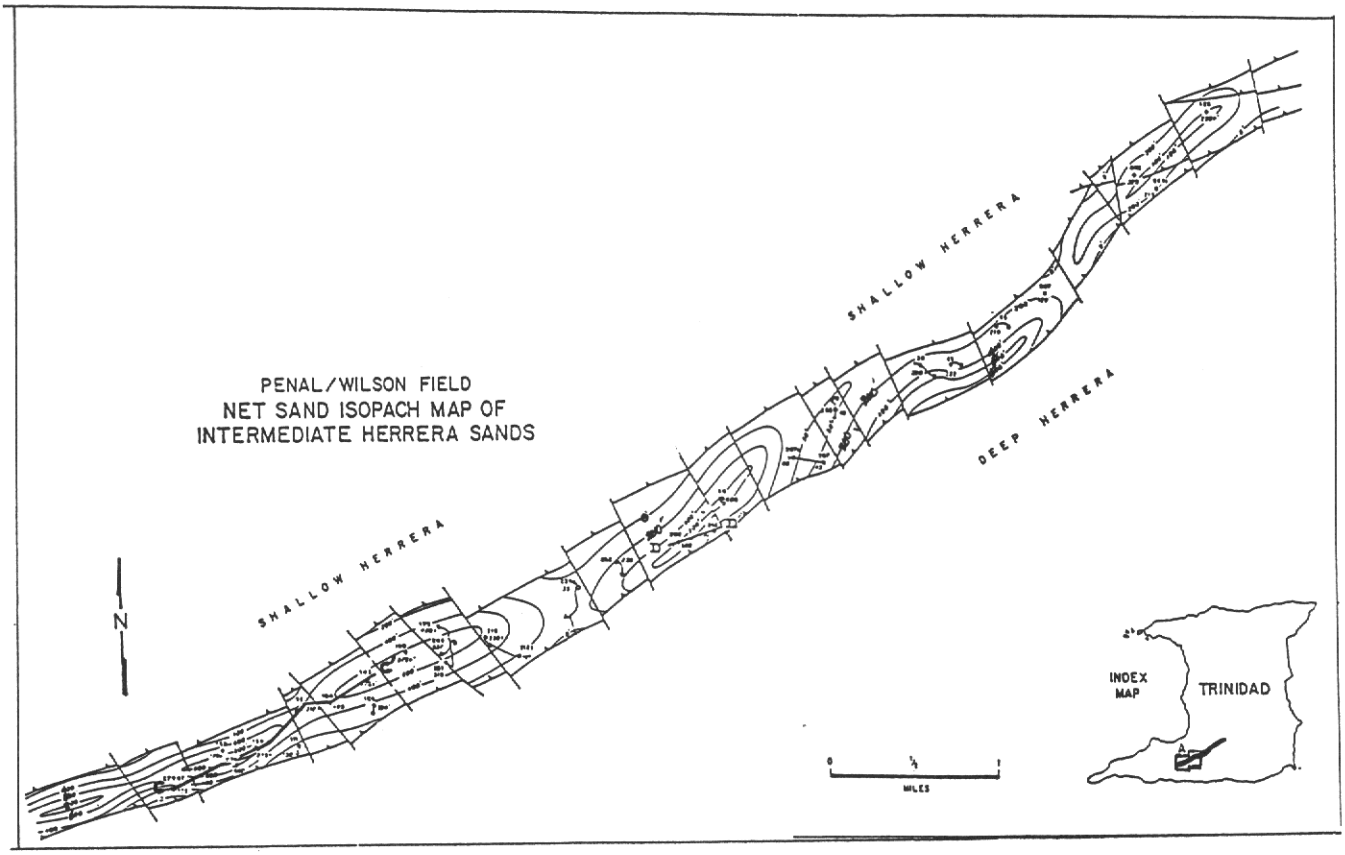


Fig. 11 Isopach Map showing NE-SW trending lobes of Herrera sand deposition.

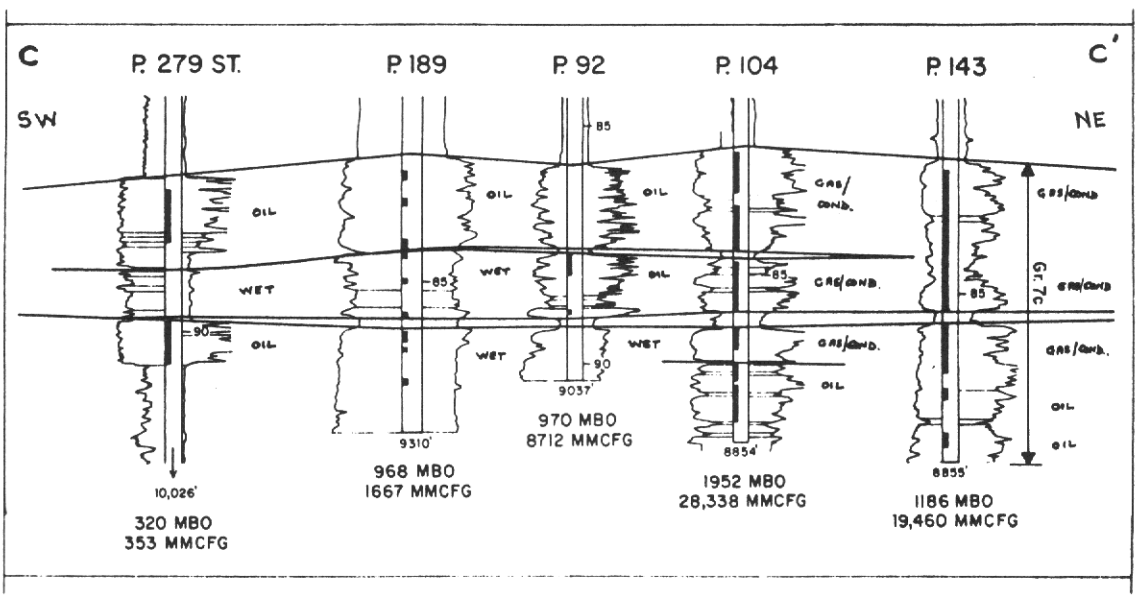


Fig. 12 Stratigraphic Section showing thick well developed oilbearing Intermediate Herrera sands.

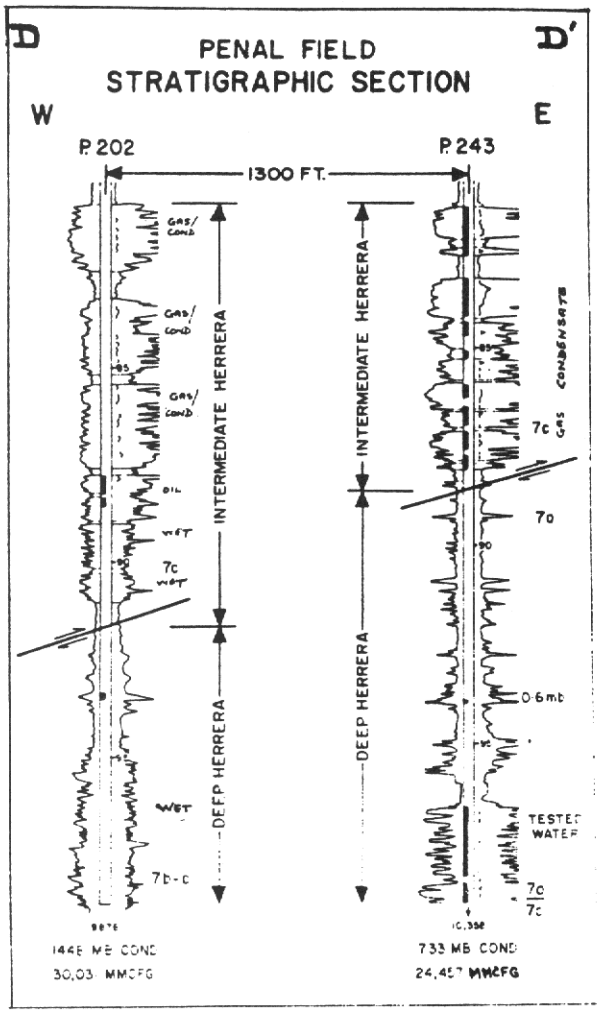


Fig. 13 The Intermediate Herrera sands thrust faulted above the "Deep" sands.

TABLE I

PENAL/WILSON FIELD

INTERMEDIATE HERRERA SAND
FIELD & RESERVOIR CHARACTERISTICS

FIRST PRODUCED	1946
FIELD AREA	1260 ACRES
FIELD LENGTH	7 MILES
NO. OF PRODUCTIVE WELLS	26
AVG. DEPTH OF SANDS	8000'-10,500'
APPROX. WELL SPACING	1200 FEET
POROSITY	18-21%
PERMEABILITY	180MD
API GRAVITY (OIL)	20° - 30°
API GRAVITY (CONDENSATE)	45° - 56°
GAS OIL RATIO (GOR)	600-20,000
DRIVE MECHANISM	SOLUTION GAS
TRAPPING MECHANISM	FAULT/SHALE SEAL
AVG. NOS THICKNESS	200-600 FEET

TABLE II

PENAL/WILSON FIELD

INTERMEDIATE HERRERA SAND
PRODUCTION AND RESERVES

CUM. PROD. OIL/COND.	14.8 MMB
CUM. PROD. GAS	260 BCF
DAILY PROD. OIL	240 BOPD
DAILY PROD. GAS	1 MMCF
PROVEN UNRECOVERED OIL RES.	124 MBO
PROVEN UNRECOVERED GAS RES.	124 MMCF
POTENTIAL OIL RES.	4.4 MMBO
POTENTIAL GAS RES.	4.4 BCF
PROSPECTIVE ACREAGE	170 ACRES

FIGURES AS OF DECEMBER, 1988

TABLE III

BARRACKPORE/MANDINGO FIELD

INTERMEDIATE HERRERA SAND
FIELD & RESERVOIR CHARACTERISTICS

FIRST PRODUCED	1954
FIELD AREA	500 ACRES
FIELD LENGTH	3.75 MILES
NO. OF PRODUCTIVE WELLS	23
AVG. DEPTH OF SANDS	5000'-10,000'
APPROX. WELL SPACING	800 FEET
POROSITY	12-20%
PERMEABILITY	50-100 MD
API GRAVITY (OIL)	22° - 25°
API GRAVITY (CONDENSATE)	—
GAS OIL RATIO (GOR)	800-1000
DRIVE MECHANISM	SOLUTION GAS
TRAPPING MECHANISM	FAULT/SHALE SEAL
AVG NOS THICKNESS	100-300 FEET

TABLE IV

BARRACKPORE/MANDINGO FIELD

INTERMEDIATE HERRERA SAND
PRODUCTION AND RESERVES

CUM. PROD. OIL/COND.	3.27 MMB
CUM. PROD. GAS	4.32 BCF
DAILY PROD. OIL	1440 BOPD
DAILY PROD. GAS	1.4 MMCF
PROVEN UNRECOVERED OIL RES.	4.3 MMB
PROVEN UNRECOVERED GAS RES.	4.3 BCF
POTENTIAL OIL RES.	10.4 MMB
POTENTIAL GAS RES.	10.4 BCF
PROSPECTIVE ACREAGE	660 ACRES

Hydrocarbon Manifestations

The hydrocarbons produced from the Barrackpore/Mandingo field are generally black oil of 22° - 25° API with some associated gas. Apart from one well, BP 372, which produced 50° API condensate and one well, BP 524, which was gas bearing, there is no evidence for any major gas-condensate/oil separation as is the case in the Penal field.

Geochemical work by K. Rodrigues (1988) indicates that the oil produced is from Upper Cretaceous Naparima Hill Argillite formation and is a parrafinic oil generated from mixed terrestrial and marine kerogens. A gas chromatogram of a typical Intermediate Herrera crude oil sample is shown in Fig. 19.

Production Characteristics

Most of the oil and gas produced from the Mandingo field has come from twenty wells drilled in the northern thrust fault segment. Some production has been obtained from three wells in the southern thrust fault segment where it seems that poor permeability related to proximity to the thrust fault is causing low productivity. The wells in the eastern part of the field are known to have high water cuts early in the production life, but yet continue to produce oil with cumulatives averaging over 200 Mbbls. per well. In the western part of the field, recently completed wells have little or no water production with cumulative oil production averaging 150 MB oil per well to date with estimated ultimate production of approximately 250 MB of oil per well. Production data indicate that the drive mechanism is solution gas drive. Major characteristics of the Barrackpore/Mandingo field are shown in the Table III.

Reserves

By December 31, 1988, the Barrackpore/Mandingo field had produced 3.32 MM bbls. of oil and 4.52 BCF of natural gas from the Intermediate Herrera sands in twenty-three active wells. Because many of the wells have only recently been drilled and completed, the proven unrecovered reserves are substantial and amount to 4.3 MMbbls. of oil. In addition, it is estimated that potential possible reserves of 10.4 MMbbls. of oil and 10.4 BCF of gas could be present over a minimum of 680 acres. Total reserves for the Barrackpore/Mandingo field are estimated at approximately 18 MMbbls. of oil and 19 BCF of natural gas (Table IV). However, mapping indicates that the Intermediate Herrera structure could extend further eastwards near to the Balata west field. This extension could add substantial amounts of potential oil and gas reserves which could be found in the Intermediate Herrera sands. Potential reserves to the west of the Barrackpore/Mandingo field are also quite substantial, some of which have already been converted to proven reserves by recent drilling since this paper was first written.

SUMMARY

The Middle Miocene age oilbearing Intermediate Herrera sands have been discovered in two fields joined together along a trend 17 miles long and approximately 2,000 feet wide. Discovery of these oilbearing sands was only made possible by drilling deeper in an area complicated at the end of Middle Miocene time by strong overfolding and major thrust faulting which separate the Herrera turbidite sands into three levels, namely the Shallow, Intermediate and Deep. Exploitation of the Intermediate Herrera sands started in 1946 and up to December 31, 1988, 18 MMbbls. of oil/condensate and 264 BCF of natural gas have been produced from the two fields. Ultimate production from this narrow thrust zone between two major faults is estimated at a minimum of 37.3 MMbbls. of oil/condensate and 283.5 BCF of natural gas. This field empahsises the need for drilling deeper in a thrust faulted zone as most of the production has been obtained from a zone which lies below shallower wet overthrust Herrera sands. Identification of and drilling for similar thrusted structure in Trinidad's southern basin may yet find substantial additional hydrocarbon in the prolific oil productive Herrera sands.

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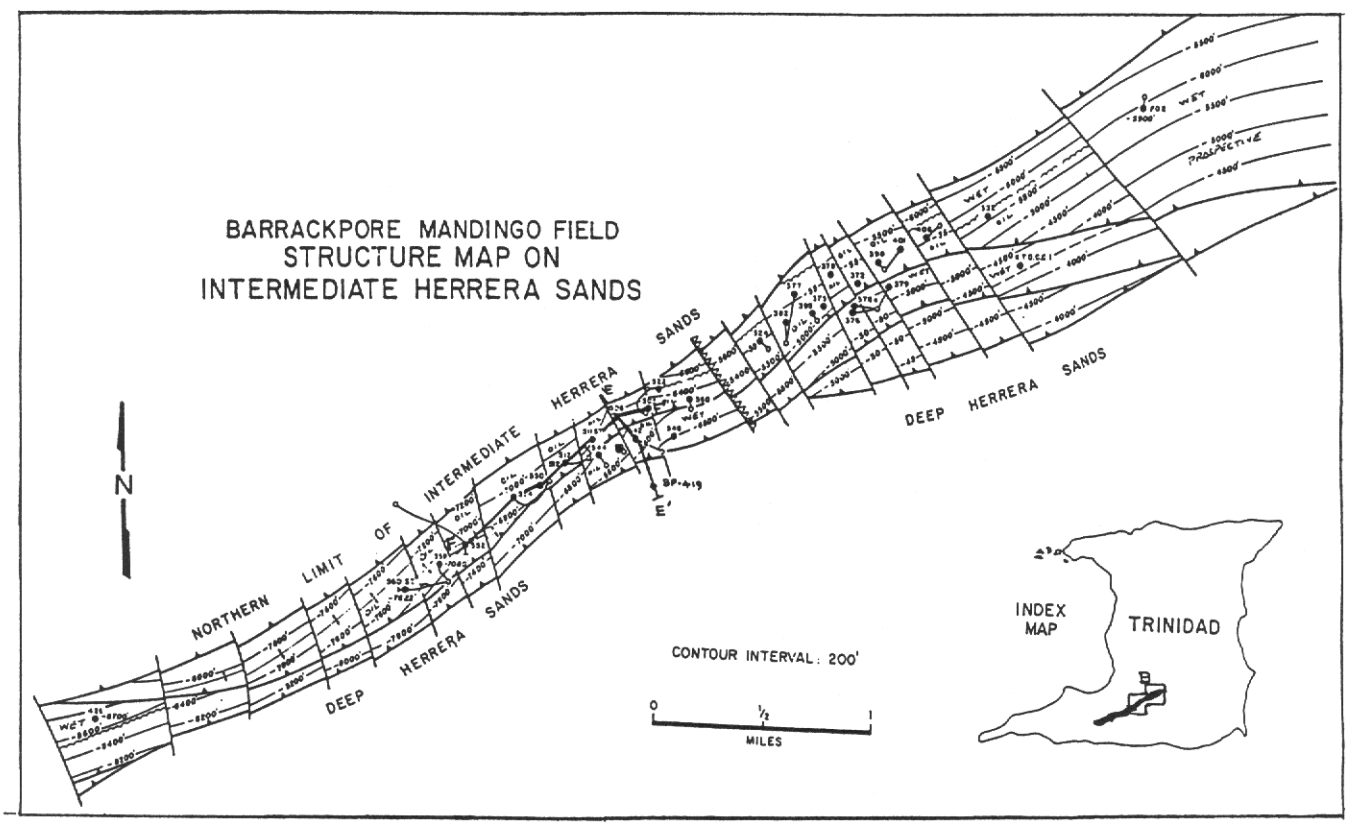
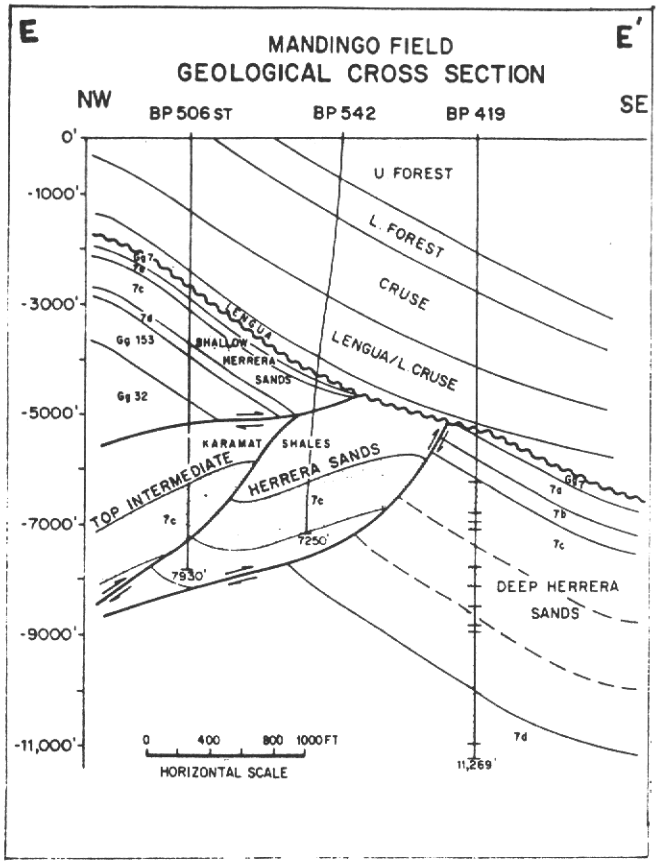


Fig. 14 Structure Map on Intermediate Herrera sands showing NE-SW trending thrust faults and NW-SE normal faults generally downthrown to the south-west. The sands dip to the north-west.



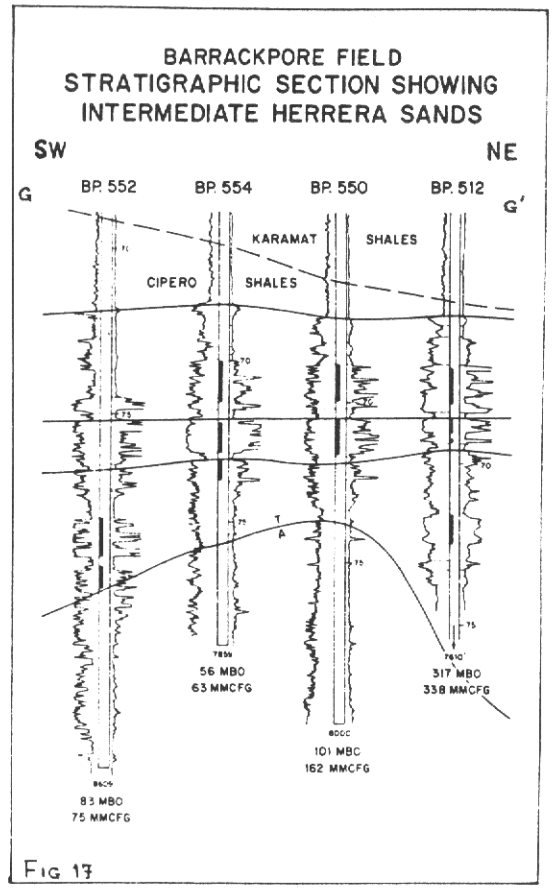


Fig. 15 Section E-E' showing Intermediate Herrera sands between the "shallow" and "Deep" Herrera sands.

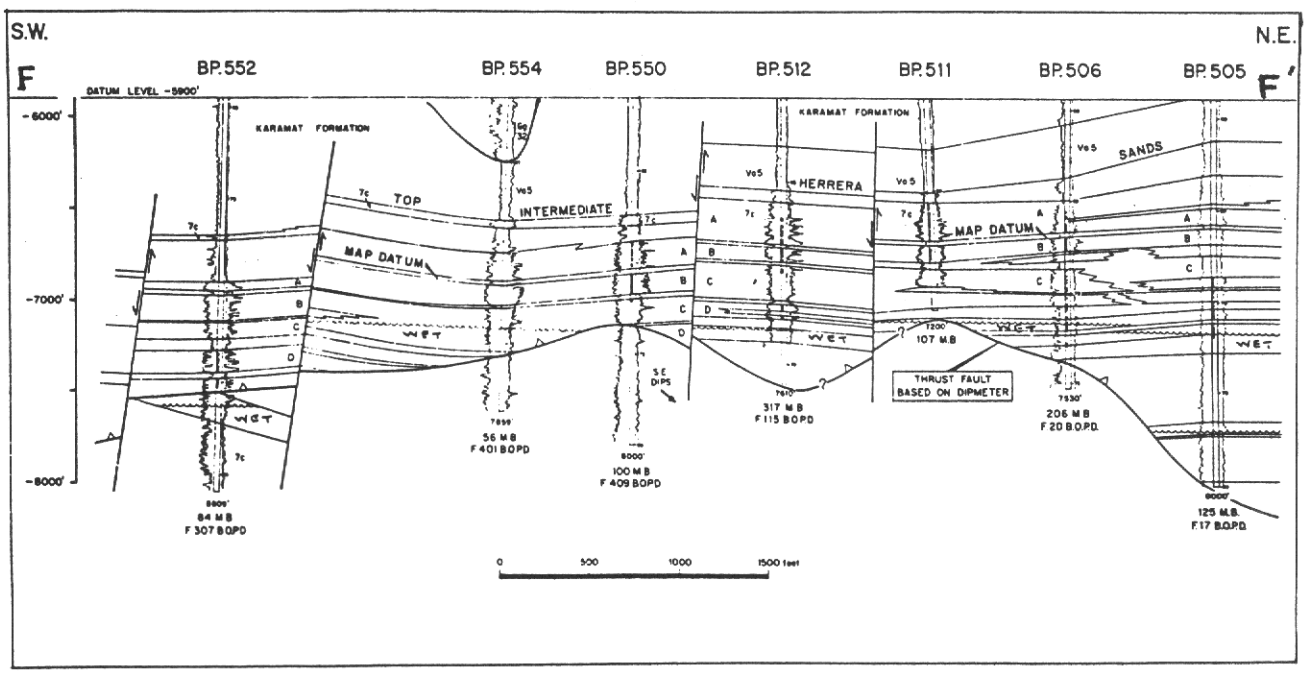


Fig. 16 Cross Section F-F' showing Intermediate Herrera sands cut by normal faults downthrown to the south-west in the Barrackpore-Mandingo field.

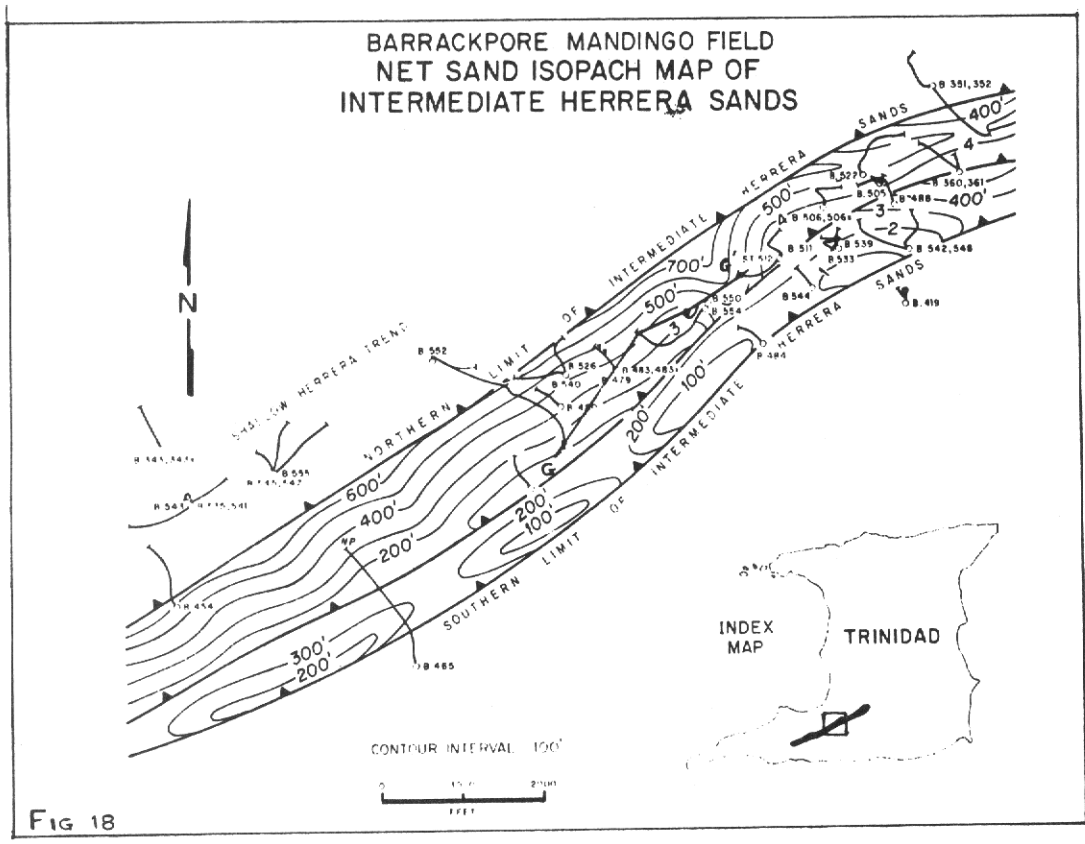

BARRACKPORE MANDINGO FIELD
NET SAND ISOPACH MAP OF
INTERMEDIATE HERRERA SANDS
N
SHALLOW HERRERA TREND
NORTHERN LIMIT OF INTERMEDIATE HERRERA SANDS
SOUTHERN LIMIT OF INTERMEDIATE HERRERA SANDS
600'
400'
200'
300'
200'
700'
500'
200'
100'
100'
400'
500'
400'
INDEX MAP
TRINIDAD
CONTOUR INTERVAL 100'
FEET

FIG 18

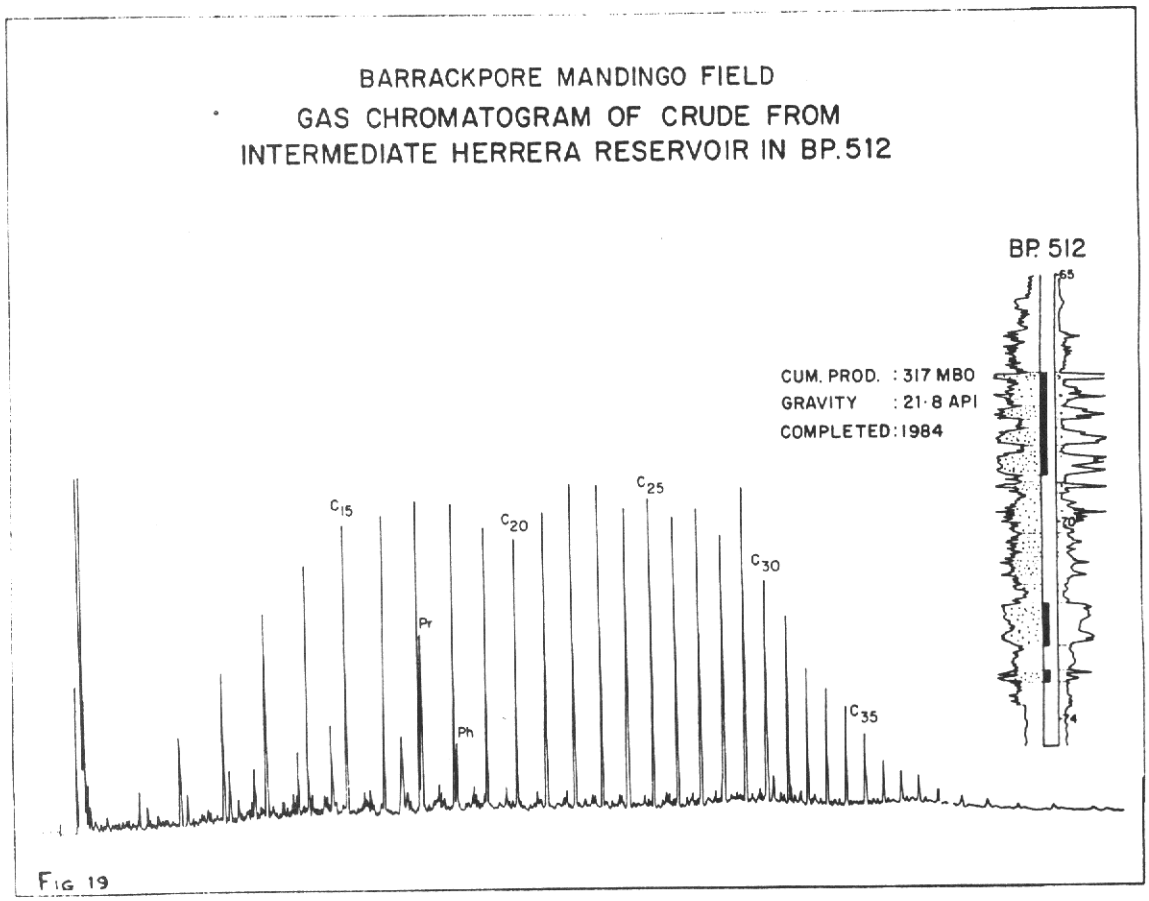

BARRACKPORE MANDINGO FIELD
GAS CHROMATOGRAM OF CRUDE FROM
INTERMEDIATE HERRERA RESERVOIR IN BP.512
BP. 512
CUM. PROD. : 317 MBO
GRAVITY : 21·8 API
COMPLETED: 1984
C15
Pr
C20
Ph
C25
C30
C35

FIG 19